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A NEW FAULT IDENTIFICATION AND PROTECTION SCHEME FOR HVDC TRANSMISSION LINE

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ABSTRACT

In this paper main aim is to analyze the performance of high voltage direct current (HVDC) system in case of internal and external fault. Differences between transient energy and other parameters of the line are analyzed in both internal and external fault. To get transient energy, voltage and current are determined at both ends of the line. Developed system identifies the internal and external fault very easily on the basis of transient energy. In the implemented scheme DC fault protection identify a fault & takes the necessary action to clear the fault. The system is implemented in MATLAB Simulink environment, the subsystem made for rectifier and inverter control scheme takes immediate actions to controlled DC power flow through transmission line. From the results obtained it is concluded that measurement transient energy can be used for implementing protection scheme.

KEYWORDS: HVDC transmission-line protection, fault component of voltage and current, transient energy.

INTRODUCTION

High Voltage Direct Current Technology (HVDC) is mostly sought after technology and need of current generation. The best part of HVDC system it has ability to transmit power over long distance with minimum transmission losses. [1] The uses of HVDC system has increased widely in last three decade. There are approximate 100 projects of HVDC system which transfer a power of 70GW. As in many situations electrical generation plant is located very far to the load, it is very much necessary to transmit the power over a long distance with minimal losses.[2] Hence, HVDC will definitely increase in coming future. The one major area to look after HVDC is, the protection of HVDC system may hamper complete power system network as it carries large amount of power which may result in huge economic loss. To overcome this disadvantage of HVDC system very fast acting protection system is required. [3] Traditionally travelling wave based methods are employed for the protection of HVDC system.

Travelling wave method suffers from a disadvantage that it gets heavily affected by electromagnetic interference and thus it required very sophisticated, complex and expensive instruments to increase the accuracy of fault detection. [4] A new scheme was introduced for low frequency differential transient energy function is adopted for ultra high voltage transmission system. Distributed parameters are needed to be considered as HVDC is deployed over a long distance. [5] In this paper use of transient energy function is done for implementing protection system for HVDC system. Distributed parameters of transmission line are calculated based on steady state parameters of the transmission line. [6]

The positive changes in transient energy function are used to determine the type of fault (internal or external). The given concept for quick protection of HVDC system is implemented using MATLAB Simulink. [7] Comprehensive test studies show that the proposed principle is simple, reliable, and practical. At the end, the

two major factors which affect performance are discussed: fault resistance and transmission distance. And the relationships between the two factors and the sensitivity of transient energy protection have been deduced. This paper is organized as follows. In Section II, the protection principle used in this paper is given. The test system is given in Section III. Test results are given in Section IV, followed by the conclusions in Section.

I. NOVEL TRANSIENT ENERGY PROTECTION PRINCIPLE

A. Overview

Fig. 1 shows a main structure diagram of the typical HVDC transmission system. The dc transmission line protection devices are installed at the two ends of the line, M and N. i_M, i_N, and u_M, u_N are dc currents and dc voltages at M and N, respectively. The positive directions of the aforementioned electrical vectors are defined in the diagram.

The transient energy of the measuring point from t_1 to t_2 is

$$\begin{cases} E_M = \int_{t_1}^{t_2} P_m(t)dt \\ E_N = \int_{t_1}^{t_2} P_n(t)dt \end{cases}.$$

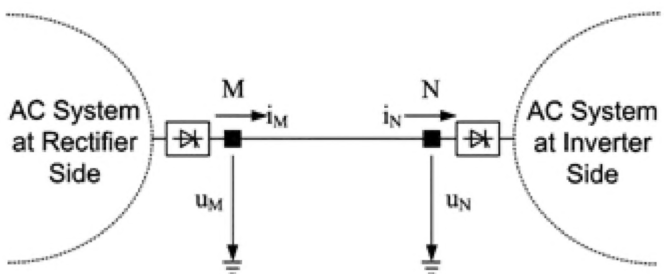

Fig. 1. Diagram of the HVDC transmission system

$$\begin{cases} \Delta E_M = \int_{t_1}^{t_2} \Delta P_m(t)dt \\ \Delta E_N = \int_{t_1}^{t_2} \Delta P_n(t)dt \end{cases}$$

Where $P_m(t)$ and $P_n(t)$ are instantaneous power of the measuring point, and $\Delta P_m(t)$ and $\Delta P_m(t)$ are their increments. By substituting $n.\Delta t$ for the continuous period from t_1 to t_2, (2) can be converted to the discrete-time form. It is shown as (3), where Δt is the sampling interval and n is the time index. Furthermore, the increments of dc voltage and dc current at the two points M and N are denoted as $\Delta u_M \Delta i_M \Delta u_N \Delta i_N$, so the increment of transient energy can be obtained as follows:

$$\begin{cases} \Delta E_M = \sum_{i=1}^{n} \Delta P_{mi} \Delta t \\ \Delta E_N = \sum_{i=1}^{n} \Delta P_{ni} \Delta t \end{cases}$$

$$\begin{cases} \Delta E_M = \sum_{i=1}^{n} \Delta u_{Mi} \Delta i_{Mi} \Delta t \\ \Delta E_N = \sum_{i=1}^{n} \Delta u_{Ni} \Delta i_{Ni} \Delta t \end{cases}.$$

Thus, the increment of transient energy in the dc line is

$$\Delta E = \Delta E_M - \Delta E_N.$$

On the steady state operation condition, $\Delta E_M = \Delta E_N =$ 0, then $\Delta E =$ 0. Under the fault conditions, the aforementioned relation is also tenable if the transmission line between M and N is defined as the ideal transmission line. However, the typical characteristics of modern HVDC transmission systems are with the long distance and bulk capacity. The distributed parameters may cause the disoperation of protective relays.

B. External Fault

An infinitesimal section of a uniformly distributed line is shown in Fig. 2(a), where R_0 is the series -resistance (Ω/km), L_0 is the series inductance (H/km), G_0 is the shunt leakage conductance (S/km), and C_0 is the shunt capacitance (F/km) [14]. The transmission-line equations are

$$-\frac{\partial u}{\partial x} = Ri + L\frac{\partial i}{\partial t}$$

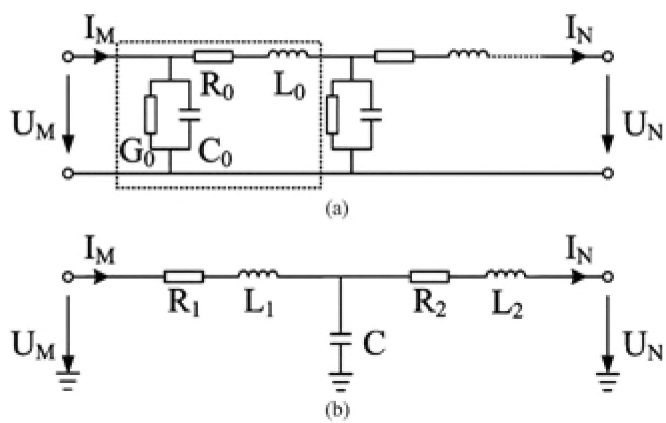

Fig. 2. Demonstration of line models. (a) Distributed parameter model
(b) Lumped parameter model with shunt capacitance

$$-\frac{\partial i}{\partial x} = Gu + C\frac{\partial u}{\partial t}.$$

For the simplification, the influence of leakage conductance is neglected in this paper. Its equivalent circuit is

shown in Fig. 2(b). The dc line to be protected is substituted by a lumped parameter model which considers the impact of shunt capacitance. The increment of voltage and current caused by the distributed parameters of the transmission line can be described as follows:

$$u_L = R_1 i_M + R_2 i_N + L_1 \frac{di_M}{dt} + L_2 \frac{di_N}{dt}$$
$$i_C = C \frac{du_C}{dt}$$

$$u_L = u_M - u_N$$

Where,

u_L= Voltage drop

i_C = Charging current

R_1, R_2 = Resistance of the dc overhead line

L_1, L_2 = Self inductance of the dc overhead line
C = Capacitor voltage by equivalent shunt capacitance
u_C= Capacitor voltage by equivalent shunt capacitance

Fig. 3(a) shows that the series inductance of dc transmission line has an effect on the protective relay during the external fault at the inverter side. The equivalent system impedance is smaller with fault F_1 than normal operation. Therefore, the volt-ages at two ends of the dc transmission line will drop rapidly. In Fig. 3(b), there is a superimposed fault current i_f, so we can obtain the transient currents at two ends of the dc transmission line under fault F_1

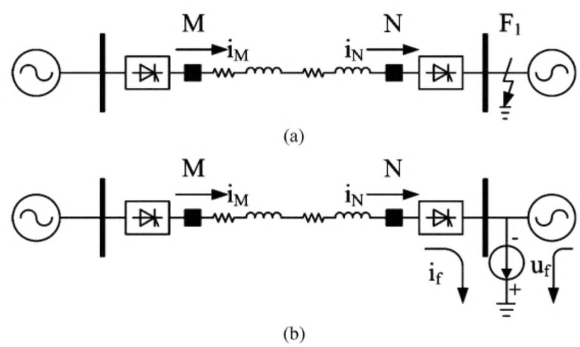

Fig. 3. External fault at the inverter side considering the series inductance of the dc transmission line
(a) Diagram of the external fault. (b) Superimposed circuit for the external fault

$$u_L = R_1 i'_M + R_2 i'_N + L_1 \frac{di'_M}{dt} + L_2 \frac{di'_N}{dt}.$$

And

$$u'_M - u'_N = u_L.$$

Before the fault F1, we have

$$u_M - u_N = R_1 i_M + R_2 i_N.$$

That means

$$\begin{cases} \Delta u_M < 0 \quad \text{and} \quad \Delta u_N < 0 \\ |\Delta u_M| < |\Delta u_N| \end{cases}. \qquad (10)$$

The dc transmission protection is also affected by the shunt capacitance of the dc line. Under normal operation conditions, there is the shunt capacitance between the overhead dc line and ground. Thus, the capacitance current is discharged from the shunt capacitance to the dc line with the fault . In Fig. 4(a), the equivalent capacitance and the discharging current are represented. In Fig. 4(b), an equivalent current source is used to substitute for the discharging current under the transient-state condition. According to (9), the equivalent discharge current of the dc line is

$$i_C = C\frac{du_C}{dt}.$$

So the transient currents of the dc line under the fault can be obtained

$$\begin{cases} i'_M = i_M + i_f - \frac{1}{2}i_C \\ i'_N = i_N + i_f + \frac{1}{2}i_C \end{cases}.$$

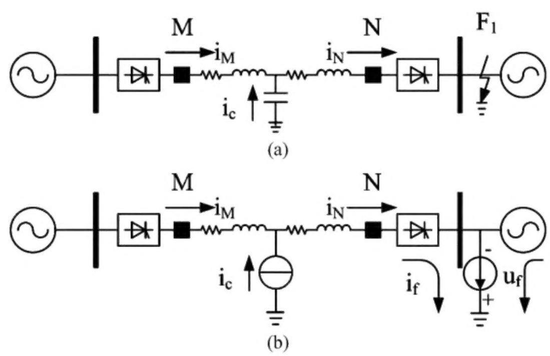

Fig. 4. External fault at the inverter side considering the shunt capacitance of the dc transmission line
(a) Diagram of the external fault. (b) Superimposed circuit for the external fault. And the increments of two transient currents are

$$\begin{cases} \Delta i_M = i_f - \frac{1}{2}i_C \\ \Delta i_N = i_f + \frac{1}{2}i_C \end{cases}.$$

Since $i_f > i_C$, there is

$$\begin{cases} \Delta i_M > 0 \quad \text{and} \quad \Delta i_N > 0 \\ |\Delta i_M| < |\Delta i_N| \end{cases}. \qquad (11)$$

Substitution of (10) and (11) into (4), then yields

$$\begin{cases} \Delta u_M \Delta i_M < 0 \quad \text{and} \quad \Delta u_N \Delta i_N < 0 \\ |\Delta u_M \Delta i_M| < |\Delta u_N \Delta i_N| \end{cases}.$$

Substituting these relationships into (5), there is

$$\Delta E > 0.$$

According to the aforementioned procedures, the ac fault at the rectifier side can also be analyzed. And a similar conclusion can be obtained

C. Internal Fault With the internal fault occurring as illustrated in Fig. 5(a), the voltages of at two ends of the dc line drop sharply. The superimposed circuit of the HVDC transmission system is shown in Fig. 5(b), where the additional fault voltage is source and is the additional fault current. On this condition, the current always

ascends while descends. So the increment of transient voltage and current can be concluded as

$$\begin{cases} \Delta u_M < 0 \\ \Delta u_N < 0 \end{cases}$$
$$\begin{cases} \Delta i_M > 0 \\ \Delta i_N < 0 \end{cases}.$$

Substituting these relationships into (4), we have

$$\begin{cases} \Delta E_M < 0 \\ \Delta E_N > 0 \end{cases}.$$

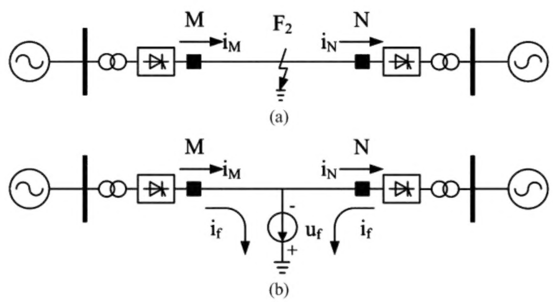

Fig. 5. Internal fault at the dc transmission line (a) Internal fault in the dc line. (b) Superimposed circuit for the internal fault.

Obviously, there is In other words, the difference of transient energy between two ends of the dc line is negative under internal faults.

D. Protection Scheme Based on Transient Energy Based on the aforementioned analysis, the transient energy setting of the relay can be

$$\Delta E_{\text{set}} = k_{\text{loss}} \times k_{\text{line}} \times k_{\text{fault.r}} \times E_{\text{loss}} \qquad (12)$$

where

k_{loss}	correction coefficient considering the change of E_{loss};
k_{line}	correction coefficient considering transmission-line length;
$k_{\text{fault.r}}$	correction coefficient considering fault resistance;
E_{loss}	energy loss in the dc line;
ΔE_{set}	setting value of transient energy protection.

The terminal voltages and current at the relaying point are monitored continuously.

$$\begin{cases} |\Delta E| > \Delta E_{\text{set}} \\ \Delta E > 0. \end{cases}$$

We can distinguish it as an external fault.

$$\begin{cases} |\Delta E| > \Delta E_{\text{set}} \\ \Delta E < 0. \end{cases}$$

The internal fault can be recognized in the dc transmission line.

III. TEST SYSTEM

Table: 1Parameters of the test system

Sr. No.	Parameter
1	1000 MW,(500 kV, 2 kA), 50 Hz
2	500 kV,5000 MVA, 50 Hz
3	345 kV, 10000 MVA, 50 Hz

Two Breaker blocks apply faults on the rectifier DC side and on the inverter AC side to examine system performance. Control and Protection Systems. When fault occurs on rectifier side change in Energy is positive so the fault does not occurred on transmission line to prevent the excess of fault current immediately rectifier pulses are stopped so output voltage become zero. Similar step is taken when fault occurs on inverter side. When fault occurs on transmission line change in energy becomes less than zero so to prevent the damage pulses of both rectifier and inverter stop.

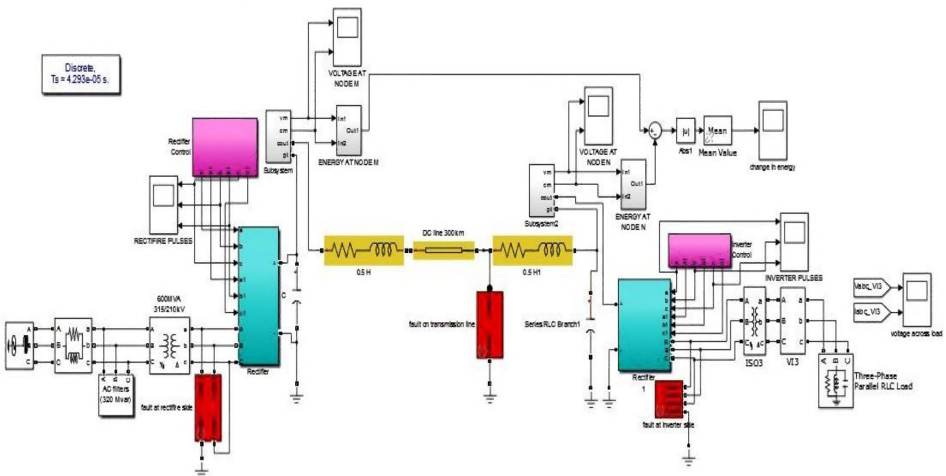

Fig. 6. Matlab Model

IV. TEST RESULTS

Simulation results for the detection of the faults (internal and external) are shown below.Following figure show the behavior of system during fault condition without protection and with protection. And protection is applied by preventing gate pulses either at inverter side or rectifier side during fault to reduce losses.

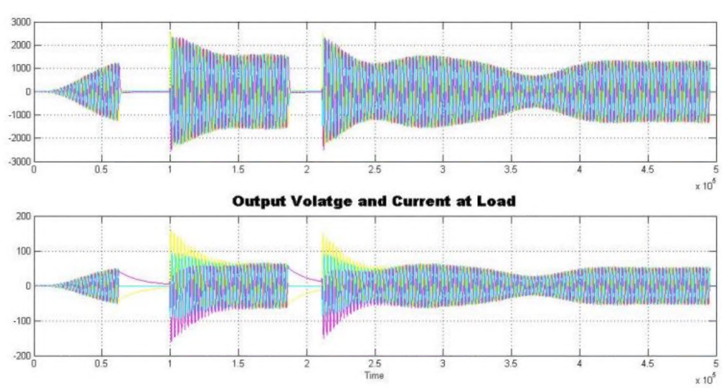

Fig.7. Output voltage and current with active protection system

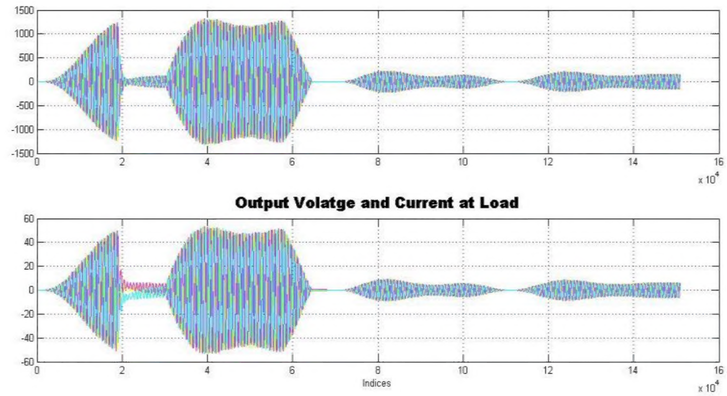

Fig.7. Output voltage and current without protection

Following Table show the comparison when fault occurs.
When balanced fault at the Inverter side

Table: 2a) with Protection

Fault Time (ms)	VM (KV)	VN (KV)	Vout (KV)	IM (KA)	IN (KA)	Iout (KA)	△E (KW/ms)
0.5	67	45	1.1	4.1	2.9	0.05	80
0.6	72	65	0.1	3.8	00	0.04	570
0.7	80	72	00	2.5	00	0.01	50
0.8	90	85	2.1	1.5	00	0.15	630
0.9	93	80	2	1.8	4	0.13	80
1	105	70	1.9	2.5	5.2	0.1	190

Table: 2b) without Protection

Fault Time(ms)	VM (KV)	VN (KV)	Vout (KV)	IM (KA)	IN (KA)	Iout (KA)	△E (KW/ms)
0.5	66	45	1.3	4	2.5	0.05	100
0.6	69	2	0.1	5.5	5	0.01	200
0.7	50	4	0.15	7.5	7	0.008	10
0.8	52	10	0.2	7.2	1	0.01	200
0.9	47	40	1	6	2	0.03	300
1	50	45	1.3	4	2.5	0.05	200

V. CONCLUSION

The fault identification of HVDC transmission system was the purpose of the study carried out in this paper.
A new method for fault identification, based on transients is proposed for HVDC transmission lines. The results have proven the proposed system performance better than the travelling wave method. All the conditions were simulated and the proposed method is found to be accurate for fault analysis. The proposed method is simple, reliable and fast.

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